इंटरनेट मानक

Disclosure to Promote the Right To Information

Whereas the Parliament of India has set out to provide a practical regime of right to information for citizens to secure access to information under the control of public authorities, in order to promote transparency and accountability in the working of every public authority, and whereas the attached publication of the Bureau of Indian Standards is of particular interest to the public, particularly disadvantaged communities and those engaged in the pursuit of education and knowledge, the attached public safety standard is made available to promote the timely dissemination of this information in an accurate manner to the public.

"जानने का अधिकार, जीने का अधिकार"
Mazdoor Kisan Shakti Sangathan
"The Right to Information, The Right to Live"

"पुराने को छोड नये के तरफ"
Jawaharlal Nehru
"Step Out From the Old to the New"

IS 9692-7 (1984): Guide on maintainability of equipment, Part 7: Collection, analysis and presentation of data related to maintainability [LITD 2: Reliability of Electronic and Electrical Components and Equipment]

"ज्ञान से एक नये भारत का निर्माण"
Satyanarayan Gangaram Pitroda
"Invent a New India Using Knowledge"

Act Number 22 of 2005
The Indian Parliament
RIGHT TO INFORMATION

Made Available By
Public.Resource.Org

"ज्ञान एक ऐसा खजाना है जो कभी चुराया नहीं जा सकता है"
Bhartṛhari—Nītiśatakam
"Knowledge is such a treasure which cannot be stolen"

BLANK PAGE

BRUTUM FULMEN

IGNORANTIA JURIS NON EXCUSAT

PROTECTED BY COPYRIGHT

"पुनर्पुष्ट १९९५"
"RE-AFFIRMED 1995"

IS : 9692 (Part 7) - 1984

(Reaffirmed 2001)

Indian Standard

GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 7 COLLECTION, ANALYSIS AND PRESENTATION OF DATA RELATED TO MAINTAINABILITY

UDC 621·38·038+621·31 : 621·3 – 7 (026)

© *Copyright* 1985

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 5 *July* 1985

Indian Standard

GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 7 COLLECTION, ANALYSIS AND PRESENTATION OF DATA RELATED TO MAINTAINABILITY

Reliability of Electronic and Electrical Components and Equipment Sectional Committee, LTDC 3

Chairman

Prof S. Sampath
Indian Institute of Technology, Kanpur

Members	*Representing*
Additional Director, Standards (S & T), RDSO	Railway Board (Ministry of Railways)
Joint Director, Standards (S & T)-III, RDSO (*Alternate*)	
Shri S. P. Bhatikar	All India Radio, New Delhi
Shri K. B. Menon (*Alternate*)	
Dr K. Chandra	National Physical Laboratory (CSIR), New Delhi
Shri Charanjit Singh	Hindustan Aeronautics Ltd, Hyderabad
Wg Cdr K. Suresh Babu (*Alternate*)	
Dr P. K. Dutta	Peico Electronics and Electricals Ltd, Bombay
Shri V. Narayanan (*Alternate*)	
Shri B. P. Ghosh	National Test House, Calcutta
Shri B. C. Mukherjee (*Alternate*)	
Shri A. P. Gupta	Instrumentation Ltd, Kota
Shri I. S. Sulakh (*Alternate*)	
Shri R. K. Jayadev	Overseas Communication Services, Bombay
Shri Hardev Singh (*Alternate*)	
Brig L. G. Ketkar	Ministry of Defence (DGI)
Lt-Col V. K. Khanna (*Alternate*)	
Shri S. P. Kulkarni	The Radio Electronic & Television Manufacturers' Association, Bombay
Shri S. M. Khursale (*Alternate*)	
Shri K. M. Mankad	Electronics Corporation of India Ltd, Hyderabad
Shri B. Bhaskar Rao (*Alternate*)	
Shri D. C. Mehta	Directorate General of Civil Aviation, New Delhi
Shri R. V. Israni (*Alternate*)	

(*Continued on page* 2)

© *Copyright* 1985
INDIAN STANDARDS INSTITUTION
This publication is protected under the *Indian Copyright Act* (XIV of 1957) and reproduction in whole or in part by any means except with written permission of the publisher shall be deemed to be an infringement of copyright under the said Act.

(*Continued from page* 1)

Members	*Representing*
Shri H. V. Mehta	Posts and Telegraphs Board, New Delhi
Shri S. Ramalingam (*Alternate*)	
Shri S. R. Mehta	Indian Electrical Manufacturers' Association, Bombay
Shri T. C. Gosalia (*Alternate*)	
Dr K. B. Misra	In personal capacity (*Department of Electrical Engineering, Indian Institute of Technology, Kharagpur*)
Shri K. R. Anandakumaran Nair	Lucas-TVS Ltd, Madras
Shri C. Ranganathan (*Alternate*)	
Shri D. V. Petkar	Bhabha Atomic Research Centre, Trombay, Bombay
Shri A. K. Babar (*Alternate*)	
Shri P. S. K. Prasad	Bharat Electronics Ltd, Bangalore
Shri K. Ramgopal	ISRO Satellite Centre (ISAC), Bangalore
Shri Siharan De (*Alternate*)	
Shri R. Somasundaram	Directorate of Technical Development and Production (AIR), Ministry of Defence
Shri R. N. Sharma (*Alternate*)	
Shri H. C. Tewari	Central Electricity Authority, New Delhi
Shri D. P. Sinha (*Alternate*)	
Brig J. Varghese	Ministry of Defence (R & D)
Shri P. K. Shukla (*Alternate*)	
Shri B. Viresalingam	Indian Telephone Industries Ltd, Bangalore
Shri V. Muthaiah (*Alternate*)	
Dr R. P. Wadhwa	Department of Electronics, New Delhi
Shri E. G. Nagarajan (*Alternate*)	
Shri N. Srinivasan, Director (Electronics) (*Secretary*)	Director General, ISI (*Ex-officio Member*)

Study of Statistical Problems of Reliability of Electronic and Electrical Items Subcommittee, LTDC 3 : 1

Convener	
Dr P. K. Dutta	Peico Electronics & Electricals Ltd, Bombay
Members	
Brig R. C. Dhingra	Electronics Regional Test Laboratory (North), New Delhi
Shri S. Mitra (*Alternate*)	
Lt-Col G. R. Malhan	Ministry of Defence (DGI)
Maj Rajan Mannil (*Alternate*)	
Shri N. C. Mishra	Telecommunication Research Centre, New Delhi
Shri T. S. Kuppuswami (*Alternate*)	
Shri V. Narayana	Indian Statistical Institute, Hyderabad
Shri P. S. K. Prasad	Bharat Electronics Ltd, Bangalore
Shri K. Ramgopal	ISRO Satellite Centre (ISAC), Bangalore
Shri P. K. Shukla	Ministry of Defence (R & D)
Dr Y. V. Somayajulu	National Physical Laboratory (CSIR), New Delhi
Shri V. N. Sharma (*Alternate*)	

Indian Standard

GUIDE ON MAINTAINABILITY OF EQUIPMENT

PART 7 COLLECTION, ANALYSIS AND PRESENTATION OF DATA RELATED TO MAINTAINABILITY

0. FOREWORD

0.1 This Indian Standard (Part 7) was adopted by the Indian Standards Institution on 16 July 1984, after the draft finalized by the Reliability of Electronic and Electrical Components and Equipment Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This guide is intended to make recommendations for the standardization of maintainability practices, and to stimulate ideas in the maintainability field. Organizations acquiring items will find the guide useful in assisting them in defining maintainability requirements and in associated programmes. Item suppliers will benefit from use of the guide, gaining an understanding of the requirements for achieving and verifying maintainability objectives.

0.3 This standard, Part 7 in the series on ' Guide on maintainability of equipment ' is intended to present a suggested approach for the collection, analysis and presentation of data related to maintainability. The other parts of this standard are as follows:

Part 1 Introduction to maintainability
Part 2 Maintainability requirements in specifications and contracts
Part 3 Maintainability programme
Part 4 Test and diagnostic procedures
Part 5 Maintainability studies during the design phase
Part 6 Maintainability verification

0.4 In the preparation of this standard, assistance has been derived from the IEC Document 56 (Secretariat) 157 Draft—' Guide on maintainability of equipment: Part 7 Collection, analysis and presentation of data related to maintainability ', issued by the International Electrotechnical Commission (IEC).

0.5 This standard is one of a series of Indian Standards on reliability of electronic and electrical components and equipment. A list of standards published so far in this series is given on 4th cover page.

1. SCOPE

1.1 This standard (Part 7) gives information on collection, analysis and presentation of data related to maintainability.

2. TERMS AND DEFINITIONS

2.1 For the purpose of this standard, the following definitions shall apply in addition to those specified in IS : 1885 (Part 39)-1979* and IS : 7690-1975†.

2.1.1 *Maintenance Policy* — A description of the inter-relationship between levels of maintenance, indenture levels, and lines of maintenance to be applied for the maintenance of an item.

2.1.2 *Maintenance Concept* — Application of a general maintenance policy to a specific item.

3. INTRODUCTION

3.1 Maintainability related data are required at several points during the item life cycle for evaluation purposes. It is the objective of this part of the guide on maintainability of equipment to provide an overview of the considerations to be taken in the collection, analysis and presentation of maintainability related data.

3.2 Collection, analysis and presentation of maintainability related data may be required during and at the completion of design and during item production and operation. Such data are typically submitted by the item supplier to the intended user in a maintainability data report which presents the data along with the supporting rationale. Key maintainability characteristics of concern are corrective and preventive maintenance downtime and manhours. Maintenance support information should also be provided defining the personnel and facilities required.

3.3 In the presentation of maintainability related data, it is important to consider the maintenance concept, the definitions of terms, the description of data sources, the analysis procedures, and the method for displaying the data. The suggested scope for each of these factors is outlined in this part of the guide.

---

*Electrotechnical vocabulary: Part 39 Reliability of electronic and electrical items (*first revision*).

†Mathematical guide to the terms and definitions for reliability of electronic equipment and components (or parts) used therein.

4. MAINTENANCE CONCEPT DEFINITION

4.1 In order to provide a clear understanding of the maintainability related data to be presented, it is essential that the item maintenance concept for which the data is applicable is defined. The type of information that typically is required to describe the applicable maintenance concept is illustrated in Appendix A.

5. DATA SOURCES

5.1 General — Maintainability related data may be developed from several sources such as the following:

a) Historical data from similar items,
b) Item design/manufacturing data, and
c) Item demonstration and field data.

5.1.1 Points for consideration in describing each of these data sources are given in **5.2** to **5.4**.

5.2 Historical Data — The origin of the historical data (field operation, repairshop experience) and the item on which they are based should be described and the rationale for their applicability to the current item presented. Methods used to collect the data along with training and skill level of maintenance personnel observed should be stated. Differences that could be expected to effect the applicability of historical data to the item under consideration should be discussed [*see* IS : 9692 (Part 6)-1983*].

Historical data should primarliy be used during the concept definition phase for specification purposes. In later phases of the item life cycle, they should be considered in relation to actual data gained on the current item itself.

5.3 Item Design/Manufacturing Data — If maintainability related data are developed from data generated during the design/manufacturing phase (development tests, manufacturing or assembly lines) through the use of design analysis or prediction, the method used shall be identified. A discussion should be provided of how the method was selected and applied along with noting any possible limitation in data accuracy.

Item qualification and acceptance with regard to maintainability should primarily be based on design/manufacturing data.

---

*Guide on maintainability of equipment: Part 6 Maintainability verification.

5.4 Item Demonstration and Field Data — Maintainability related data may be developed from demonstration tests conducted using prototype hardware or from data generated during item use (repair workshop, field operations). Methods of selecting maintenance actions, data monitoring and recording techniques should be described. Skill level of maintenance personnel and the training they had received should be noted. Several maintainability verification techniques have been stipulated in IS : 9692 (Part 6)-1983*. The feedback of demonstration and field data is the primary basis for sustaining engineering activities during the in-service phase of the item life cycle.

6. ANALYSIS PROCEDURES

6.1 When presenting maintainability related data for the purpose of testing the compliance with stated maintainability requirements as well as for determination purposes, the analysis procedures used should be described. The points of concern include the following:

a) Data editing,
b) Distribution analysis, and
c) Parameter computation.

6.1.1 *Data Editing* — Actions taken to assure the accuracy, completeness and validity of the data should be described. If any censoring is performed, the rules used and reasons for performing these operations should be presented.

6.1.2 *Distribution Analysis* — If the maintainability related data is to be treated parametrically it is necessary to determine the distribution of the basic data. The method to be used in testing the distribution form should be described along with the rationale for its selection. Common methods for distribution analysis include the Chi square, Kolmogorov-Smirnov and graphical tests. Appendix B to this standard provides further information on distribution analysis methods.

6.1.3 *Parameter Computation* — The basis for computing all maintainability parameters to be presented should be stated. If selected parameters are to be computed on a cumulative or interval basis, the method to be used should be detailed. If maintainability mathematical models are to be used, they should be fully described. Appendix B provides guidance on the computation of the arithmetic and geometric means, confidence limits and selected fractiles for the lognormal, normal and multimodal distributions, which are most commonly used in maintainability. For other distribution types, corresponding values can be found in statistical textbooks.

---

*Guide on maintainability of equipment: Part 6 Maintainability verification

7. DATA DISPLAY

7.1 Maintenance data displays are typically developed for the following:

a) Corrective actions, and
b) Preventive actions.

In addition, maintenance support data should be presented to provide necessary background information.

7.2 Corrective Maintenance — Corrective maintenance time is typically expressed in active repair time comprised of several subelements. Appendix C presents a typical summary recording of the details of a series of active repair elements included in corrective maintenance. The form provides for identifying the failed unit (unit reference), the type of failure considered (fault), the technician(s) performing maintenance (name), the number of men required, and the several elements of downtime. It would be applicable for data derived from development or operational tests. Data derived from historical or prediction sources may be presented on the basis of expected average (mean) or median values rather than by individual tasks. Appendix D illustrates the form that data from these sources could take along with summarized (averaged) test data. In this form, for each major sub unit of the item, the average active repair time is shown along with its standard deviation. If desired, selected fractiles could be displayed in lieu of the standard deviation, that is, 95th fractile.

Other parameters sometimes used to characterize certain aspects of corrective maintenance include the following:

a) Automatic failure detection ratio (item operating),
b) Automatic failure recovery ratio,
c) Automatic or manual failure localizing with accuracy of 1 to *n* plug in units,
d) Efficiency of automatic or manual repair procedures, and
e) Mean or fractile active recovery time.

Average values for these parameters may be derived from historical or prediction sources and summarized test data.

7.3 Preventive Maintenance — Presentation of preventive maintenance data requires that the duration of the tasks be identified along with their frequency. Appendix E illustrates the form to present these data. Preventive maintenance times are usually expressed as active preventive maintenance time. Observed non-active preventive maintenance down time can be added when necessary. To aid maintenance planning estimated maintenance manhours for each task are also desired. In addition to the detailed task information an overall summary of preventive maintenance times should be presented.

7.4 Maintenance Support Data — Maintenance support data may be required to aid the item user to properly plan for its support. Appendix F illustrates the type of information that may be required. Principal data elements should be supported by information on the recommended maintenance concept, training requirements, special tools, or other support equipment and technical documentation used. Additionally the item maintenance requirements should be detailed in terms of major maintenance tasks to be performed and the requirements for personnel skills and support equipment, along with their impact on downtime and manhours.

Further parameters such as the following can sometimes be used to cover certain maintenance support aspects and may be added as required:

a) Mean or fractile administrative recovery time,

b) Mean or fractile administrative repair time,

c) Spare parts usability ratio,

d) Mean or fractile delivery time of spare parts repair, and

e) Mean or fractile delivery time of software repair.

APPENDIX A

(*Clause* 4.1)

EXAMPLE OF THE MAINTENANCE CONCEPT INFORMATION

ITEM REFERENCE ______________________ DATE ______________

ITEM DESCRIPTION ______________________________

ITEM FUNCTION ______________________________

____

MAINTENANCE CONCEPT

LINES OF MAINTENANCE*	REPLACEMENT LEVEL	SKILL REQUIREMENTS	SUPPORT EQUIPMENT REQUIREMENTS	TECHNICAL DOCUMENTATION REQUIREMENTS	TRAINING REQUIREMENTS
1. On-Item (Organizational)	________	________	________	________	________
2. Local (Intermediate)	________	________	________	________	________
3. Depot	________	________	________	________	________

---

*Lines of maintenance are illustrative only. The lines used should be consistent with item maintenance needs and use location.

APPENDIX B

(*Clauses* 6.1.2 *and* 6.1.3)

MAINTENANCE DATA ANALYSIS METHODS

B-1. LOGNORMAL DISTRIBUTION

B-1.1 A random variable x has a lognormal probability distribution if the logarithm of the variable is distributed normally. The lognormal probability density function is:

$$f(x) = \frac{1}{x \sigma \sqrt{2 \pi}} \exp \left\{ - \frac{1}{2 \sigma^2} (\log_e x - \theta)^2 \right\}, 0 < x < \infty \quad (1)$$

If x is the individual maintenance time, then the probability density of $y = \log_e x$ is normal, with mean θ and variance σ^2. The maximum likelihood estimators of θ and σ^2 are given by:

$$\hat{\theta} = \frac{1}{n} \sum_{i=1}^{n} \log_e x_i \quad (2)$$

$$\hat{\sigma}^2 = \frac{1}{n-1} \sum_{i=1}^{n} (\log_e x_i - \hat{\theta})^2 \quad (3)$$

The variance of these estimators is respectively given by:

$$V(\hat{\theta}) = \sigma^2/n \quad (4)$$

$$V(\hat{\sigma}^2) = 2 \sigma^4 (n - 1) \quad (5)$$

For θ, p percent confidence interval is given by:

$$\left(\hat{\theta} - t_{p,\, n-1}\, \hat{\sigma}/\sqrt{n},\ \hat{\theta} + t_{p,\, n-1}\, \hat{\sigma}/\sqrt{n} \right) \quad (6)$$

where $t_{p,\, n-1}$ is the p fractile of the t distribution with $(n-1)$ degrees of freedom.

For σ^2, a p percent confidence interval is

$$\left(\frac{(n-1)\, \hat{\sigma}^2}{\chi^2_{p_1,\, n-1}},\ \frac{(n-1)\, \hat{\sigma}^2}{\chi^2_{p_2,\, n-1}} \right) \quad (7)$$

where $\chi^2_{p_1,\, n-1}$ is the p_1 fractile of the χ^2 distribution with $(n-1)$ degrees of freedom and $p_1 - p_2 = p$.

Several important moments and distributional properties of the lognormal distribution are presented below:

Mean $= e^{\theta+\sigma^2/2}$ (8)

Variance $= e^{2\theta+\sigma^2} \left(e^{\sigma^2} - 1 \right)$ (9)

Median = geometric mean $= e^{\theta}$ (10)

Mode $= e^{\theta-\sigma^2}$ (11)

p fractile $= e^{\theta} + Z_p\sigma$, where Z_p is normal deviate (12)

$$= \int_{-\infty}^{Z_p} \frac{1}{\sqrt{2\pi}} e^{-z^2/2} dz$$

Coefficient of variation $= \left(e^{\sigma^2} - 1 \right)$ (13)

The lognormal is a positively skewed distribution, with degree of skewness increasing as σ^2 increases. From the above formulae, it is seen, that mode < median < mean. Because of the parameters θ and σ^2, the lognormal is a relatively flexible distribution.

B-2. NORMAL DISTRIBUTION

B-2.1 The probability density of the normal distribution is given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}, \quad -\infty < x < +\infty \qquad (14)$$

Parameter estimates are as follows:

$$\hat{\mu} = \text{mean} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (15)$$

where, x_i = individual maintenance times

n = number of maintenance actions

$$\hat{\sigma}^2 = \text{variance} = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \hat{\mu})^2 \qquad (16)$$

The variances of $\hat{\mu}$ and $\hat{\sigma}^2$ for large sample sizes are given by:

$$V (\hat{\mu}) = \frac{\sigma^2}{n} \qquad (17)$$

$$V (\hat{\sigma}^2) = 2 \sigma^4 (n - 1) \qquad (18)$$

For μ, a p percent confidence interval is given by:

$$\left(\hat{\mu} - t_{p,\, n-1}\, \hat{\sigma}/\sqrt{n},\ \hat{\mu} + t_{p,\, n-1}\, \hat{\sigma}/\sqrt{n} \right) \tag{19}$$

where $t_{p,\, n-1}$ is the p fractile of the t distribution with ($n - 1$) degrees of freedom.

For σ^2, a p percent confidence interval is

$$\left(\frac{(n-1)\,\hat{\sigma}^2}{\chi^2_{p_1,\, n-1}},\ \frac{(n-1)\,\hat{\sigma}^2}{\chi^2_{p_2,\, n-1}} \right) \tag{20}$$

where $\chi^2_{p_i,\, n-1}$ is the p_i fractile of the χ^2 distribution with ($n - 1$) degrees of freedom and $p_1 - p_2 = p$.

The p fractile X_p is given by:

$$X_p = \mu + z_p \sigma \tag{21}$$

where

$$z = \frac{X - \mu}{\sigma} \tag{22}$$

$$p = \int_{-\infty}^{Z_p} \frac{1}{\sqrt{2\pi}}\, e^{-z^2/2}\, dz \tag{23}$$

Values for Z_p may be obtained from standard tables for the normal distribution.

B-3. MULTIMODAL DISTRIBUTION

B-3.1 Due to the non-homogeneous nature of the design for some items, the observed maintenance time distribution may be found to have two or more modes. Such cases may be identified if the composite data fails to pass a lognormal goodness-of-fit test. A further verification may be accomplished by separating the data into logical groups based on its design source and performing standard statistical tests to determine if the sample data groups came from different populations. If the populations are judged to be different and also determined to be individually lognormal, the procedures outlined in subsequent paragraphs may be used. If they are determined to be from different groups but not lognormal, the appropriate distribution form should be substituted for the lognormal distribution in the method outlined.

The probability distribution function *pdf*, of a mixed distribution of *N* types of maintenance times is:

$f(x) = m_1 f_1(X) + \ldots\ldots\ldots + m_N f_N(X)$ where $f_i(X)$ is the *pdf* of maintenance times of type i and $m_1 + m_2 \ldots\ldots\ldots + m_N = 1$.

The m_i values may be estimated by the relationship:

$$m_i = \frac{\lambda i}{\sum_{i=1}^{N} \lambda_i} \tag{24}$$

where

λ_i = failure rate of type i.

Let the *pdf* of the i-th type of maintenance actions be denoted by:

$$f_i(X) = \frac{1}{X \sigma_i \sqrt{2\pi}} \exp\left[-\frac{1}{2\sigma_i^2}(\log_e x - \theta_i)^2\right] \tag{25}$$

with mean $\mu_i = e^{\theta_i + \sigma_i^2/2}$ (26)

and variances $v_i = e^{2\theta_i + \sigma_i^2}\left(e^{\sigma_i^2} - 1\right)$ (27)

Then the *pdf* of the mixed distribution of maintenance times X is

$$f(X) = m_1 f_1(X) + \ldots\ldots\ldots + m_N f_N(X) \tag{28}$$

with mean $\mu = m_1 \mu_1 + \ldots\ldots\ldots + m_N \mu_N$ (29)

and variance $v = m_1(\sigma_1^2 + \mu_1^2) + \ldots + m_N(\sigma_N^2 + \mu_N^2) - \mu^2$ (30)

The p fractile X_p is determined by solving

$$m_1 F_1(X_p) + \ldots\ldots\ldots + m_N F_N(X_p) = p \tag{31}$$

for X_p, where $F_i(X) = \int_0^X f_i(z)\,dz$ is the distribution function of i-th type of maintenance action.

Solution of this equation for X_p may not be obtained in closed form but a numerical procedure may be used. One simplified approach* based

---

*I. Burr; A useful approximation to the Normal Distribution Function with Application to Simulation, *Technometrics*, 9, 1967, pp 647-651.

on a closed form approximation for the normal distribution is presented below:

a) Choose a tolerance factor, *TOL* such that estimates of X_p which yield percentile values differ by not more than *TOL* from the true value of p are acceptable (for example, $TOL = 0{\cdot}005$).

b) Choose an initial value for X_p, say X_p^*. One possibility is the smallest p fractile of the N types of maintenance times.

c) For each type of maintenance time, compute

$$z_1 = \frac{\log_e X_p^* - \theta_1}{\sigma_1} \qquad (32)$$

d) Calculate

$$Y = \sum_{i=1}^{N} m_1 [1 + (0{\cdot}644\,669\,3 + {\cdot}161\,984 z_1)^{4{\cdot}874}]^{-6{\cdot}158}$$

e) If $| Y - (1 - p) | \leqslant TOL$ then X_p^* is the estimated p-th percentile. (33)

If the absolute difference exceeds the tolerance factor, repeat steps (c) and (d) with new values of X_p^*. If $Y < 1 - p$, the next X_p^* should be increased. If $Y < 1 - p$, X_p^* should be decreased.

Example:

Assume two types of maintenance, with the following lognormal parameters:

$\theta_1 = 3{\cdot}0$	$\theta_1 = 1{\cdot}0$
$\sigma_1 = 0{\cdot}5$	$\sigma_1 = 0{\cdot}2$
$m_1 = 0{\cdot}7$	$m_1 = 0{\cdot}3$

The 90th percentile for the mixture is desired. Applying the above logarithm yields 90th percentile value of 34.

B-4. DISTRIBUTION ANALYSIS METHODS

B-4.1 Tests for the distribution form using the sample data may employ such techniques as Chi square, Kolmogorov-Smirnov, or graphical procedures employing special graph papers. Of these methods, the Kolmogorov-Smirnov or *d*-test is considered superior and will be described in more detail.

---

*I. BURR; A useful approximation to the Normal Distribution Function with Application to Simulation, *Technometrics* 9, 1967, pp 647-651.

The *d*-test is accomplished by plotting the hypothesized theoretical distribution (for example, lognormal) using, as appropriate, the observed data for parameter estimation (for example, mean and standard deviation). About this theoretical distribution, boundaries are constructed which are ± *d* probability units. Table 1 provides a limited set of the *d* values which are selected, based on data sample size and the level of significance (α) for which the test is to be conducted. The observed data distribution is next plotted. If the observed function passes outside the boundaries at any point, then the hypothesized theoretical distribution is not consistent with the data. Conversely, if the observed function always remains inside the boundaries, the hypothesis concerning the underlying distribution can not be rejected.

To illustrate the use of the technique, ane xample is provided. Table 2 presents a set of observed data which will be tested for the lognormal distribution. The natural log of each observed time was taken and the mean θ and the variance σ^2 of the log values computed. Using these values, a theoretical lognormal distribution was plotted in Fig. 1. Selecting a 5 percent significance level, with the sample size of ten, the tabled critical *d* value was found to be 0·41 (*see* Table 1). Since the estimates of θ and σ^2 are used in generating the theoretical distribution, this value is corrected by multiplying it by 0·67 yielding a result of $d = 0{\cdot}295$.

The observed maintainability function was calculated by the use of the non-parametric equation:

$$\hat{F} (X_k) = \frac{k}{n + 1} \qquad (34)$$

where

X_k = observed time of the k_{th} ordered maintenance action,

$\hat{F} (X_k)$ = estimated probability that a maintenance action is completed within X_k time units, and

n = number of observed maintenance actions.

Figure 1 shows the observed and theoretical distribution along with the Kolmogorov-Smirnov boundaries. It is seen that the observed distribution falls within the boundaries indicating that the data could have arisen from a lognormal population with a parameter $\theta = 3{\cdot}19$, $\sigma = 0{\cdot}358$.

TABLE 1 CRITICAL VALUES OF *d*, KOLMOGOROV-SMIRNOV TEST

(*Clause* B-4.1)

SL NO.	SAMPLE SIZE	LEVEL OF SIGNIFICANCE (α)			
		0·15	0·10	0·05	0·01
(1)	(2)	(3)	(4)	(5)	(6)
i)	5	0·474	0·510	0·565	0·669
ii)	10	0·342	0·368	0·410	0·490
iii)	15	0·283	0·304	0·338	0·404
iv)	20	0·246	0·264	0·294	0·356
v)	30	0·20	0·22	0·24	0·29
vi)	40	0·18	0·19	0·21	0·25
vii)	50	0·16	0·17	0·19	0·23
viii)	Over 50	$\frac{1·14}{\sqrt{n}}$	$\frac{1·22}{\sqrt{n}}$	$\frac{1·36}{\sqrt{n}}$	$\frac{1·63}{\sqrt{n}}$

NOTE — The *d* values shown are based on a complete specification of the hypothesized distribution. If sample data is used to estimate the parameter(s), multiply the tabled *d*-value by 0·80 for testing the exponential and by 0·67 for testing the normal distribution.

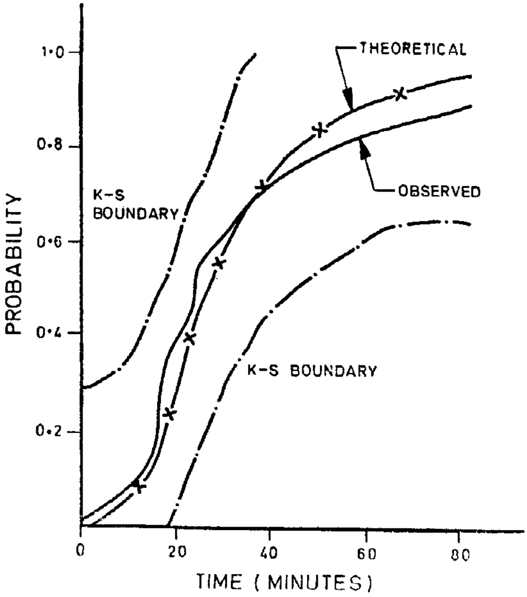

FIG. 1 EXAMPLE DISTRIBUTION ANALYSIS

TABLE 2 SAMPLE MAINTENANCE DATA SET

(*Clause* B-4.1)

RANK, k	OBSERVED TIME X_k	In (X_k)	F (X_k) CUMULATIVE PROBABILITY
(1)	(2)	(3)	(4)
i)	10	2·30	0·091
ii)	15	2·70	0·182
iii)	17	2·83	0·273
iv)	18	2·89	0·364
v)	20	3·00	0·454
vi)	22	3·09	0·548
vii)	27	3·30	0·636
viii)	35	3·56	0·767
ix)	50	3·91	0·818
x)	75	4·32	0·909

Mean (X) = 28·9 minutes.

$$\left.\begin{array}{l}\text{Mean} = (O) = 3{\cdot}19 \\ \text{Variance} (\sigma^2) = 0{\cdot}358\end{array}\right\} \text{time being given in minutes.}$$

APPENDIX C

(*Clause* 7.2)

ACTIVE REPAIR TASK DATA SUMMARY FORM

Task Number	Unit Reference	Fault	Name	Number of Men	Active Repair Time Sub Elements (Hours)					
					Diagnosis	Technical Delay	Restoration	Check	Total	Man-hours
1	LRA*-1	CR-1		1	0·2	0·1	0·1	0·1	0·5	0·5
2	LRA*-1	C-21		2	0·7	0·2	0·2	0·2	1·3	2·6
3	LRA*-5	—		—	—	—	—	—	—	—

APPENDIX D

(*Clause* 7.2)

ACTIVE REPAIR TIME SUMMARY FORM

Unit Reference	Diagnosis Time		Technical Delay		Restoration Time		Final Check Time		Total Time	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
LRA*-1	0·2	0·05	0·1	0·05	0·1	0·05	0·1	0·05	0·5	0·05
LRA*-5	0·7	0·1	0·2	0·05	0·2	0·05	0·2	0·05	1·3	0·09

*LRA — Line replaceable assembly.

APPENDIX E

(*Clause* 7.3)

PREVENTIVE MAINTENANCE SUMMARY

TASK NUMBER	UNIT REFERENCE	TASK DESCRIPTION	SPECIFIED TASK FREQUENCY	TASK PROC. REF.*	NUMBER MEN REQ.	MANHOURS	ACTIVE PREVENTIVE MAINTENANCE TIME
1	LRA-1	Clean Air Filter (Part No. 627)	Every 500 hours	A-1	1	0·5	0·5
2	LRA-1	Replace Brushes (Part No. 123)	Every 2 000 hours	A-2	2	1·5	0·75
3	....	....	....	......	...	...	......

*Reference to detailed description of preventive maintenance task procedure.

APPENDIX F

(*Clause* 7.4)

EXAMPLE OF MAINTENANCE SUPPORT DATA

Item Reference ____________________ Date ____________

Item Description ____________________

Item Function ____________________

____

Maintenance Concept ____________________

____

Training Conditions ____________________

____

Special Tools, Test or Support Equipment Used ____________________

____

Technical Documentation Used ____________________

____

ITEM MAINTENANCE CONDITIONS

Reference Number	Description	Line of Maintenance	Type Action	Personnel Skill	Support Equipment	Task Frequency	Manhours Per Task	Total Manhours